BANKSIA INTEGRIFOLIA LINNEUS FIL. INFESTATION BY XYLORYCTID MOTH LARVAE, CAPE SCHANCK, VICTORIA

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Two species of xyloryctid moth have been identified, *Xylorycta parabolella* Walker and *Scieropepla* sp., the larvae of which feed on the new leaf and branchlet tissue of *Banksia integrifolia* L. f. var. *integrifolia*. They appear to be specialist herbivores rather than seed predators, and the damage to *Banksia integrifolia* is predominantly canopy damage rather than a reduction in seed set. Infestations of these moth larvae on *Banksia integrifolia* are regionally patchy. The overall level of canopy damage in *Banksia integrifolia* woodland is relatively low (about 4%), but the level of inter-tree canopy damage is quite variable, and may be up to 10%. As the canopies appear to be able to recover from defoliation caused by xyloryctid moth larvae, interventionist management is not warranted. However, the low tree densities and increasing fragmentation of *Banksia integrifolia* woodland, coupled with repeated severe infestations of xyloryctid larvae, may still pose problems for the survival of existing mature trees in remnant *Banksia* woodland, and for the conservation of the two xyloryctid species.

BANKSIA integrifolia L. f. var. *integrifolia* woodland is still found growing over much of the Mornington Peninsula, but canopy dieback and periodic heavy infestations of moth larvae have raised concerns about the regeneration capacity and long term survival prospects of these remnant *Banksia* woodlands. However, little is known about the interactions between plant species and moths, and most Australian moths are wholly plant dependent (New 1992). It is still common for the presence of moths or their larvae to be treated simply as a damaging infestation by a pest species which needs to be controlled, and the impact of the infestation and the implications for moth species conservation is rarely considered. In evolutionary terms the Xylorictinae is a relatively recent group which has radiated in Australia in association with *Acacia* and *Eucalyptus* (New 1984). As so little is known about plant–moth interactions, the conservation of these co-evolved species may need to receive more attention.

Xyloryctid moth larvae (Lepidoptera : Oecophoridae : Xyloryctinae) are specialist feeders on species from the families Myrtaceae and Proteaceae (Powell 1980), and cause substantial damage in *Banksia* species by tunnelling in the branchlets and inflorescences (Scott 1982; Zammit & Hood 1986; Wallace & O'Dowd 1989; Röhl & Woods 1994), and feeding on leaves (Common 1970; Common 1990). Reduced reproductive capacity caused by insect larval damage to the inflorescence and seeds has been recorded in several species of *Banksia* (Scott 1982; Vaughton 1990), and associated with a number of lepidopteran and coleopteran species (Scott 1982; Hood 1985; Zammit & Hood 1986; Collins & Rebelo 1987; Wallace & O'Dowd 1989). Infestations of coleopteran larvae have also been recorded as a major contributor to the death of remnant *Banksia marginata* (Fearn 1989).

Two species of moth, *Xylorycta parabolella* Walker and *Scieropepla* sp. (Lepidoptera : Oecophoridae : Xyloryctinae) (Nielsen et al. 1996), have been identified from the infested foliage of *Banksia integrifolia*. The larvae of both species feed on the new leaf and branchlet tissue of *Banksia integrifolia*. Both species of moth larvae were found to co-exist in the same shelter, and detailed examination of the larvae, cocoons and pupa, indicated that the two species were indistinguishable until the adult hatched.

Xyloryctid moth larvae weave web and ejected waste material into a nest-like shelter which is attached to the branchlets of *Banksia integrifolia*. The shelters vary in size; small shelters are about 8 cm wide and 5 cm deep, and large shelters may be up to 25 cm wide and 15 cm deep. As many as 66 larvae have been recorded from large shelters, and 20 from small shelters. Larvae were never observed outside the shelters. The final instar larva forms a cocoon-shaped structure of silk in the shelter. This cocoon is a reddish-brown color, the same color as the shelter, but is more finely woven and has a soft down-like lining. It is fragile and easily torn open. The pupa are slender, delicate and light brown with a tapering posterior end.

Individual trees of all ages may become infested by larvae and covered in shelters, and canopy dieback may result (Fig. 1). Phytophageous insects are already well recognised as a significant contributor to canopy damage and to the general decline in health and population numbers of *Eucalyptus* species (Ohmart & Edwards 1991), but less is known about their role in the dieback of *Banksia* species.

Canopy dieback and infestation of *Banksia integrifolia* by moth larvae appears to be regionally patchy, and in 1986 and 1987 was restricted to the Main Creek area and some small areas at Point Leo, near Cape Schanck, Victoria (Fig. 2). Populations of *Banksia integrifolia* at Mt Martha, on the northwestern side of the Peninsula, showed no visible signs of dieback or infestation. The infested area of Cape Schanck is open woodland, characterised by *Banksia integrifolia*, *Eucalyptus pauciflora* and *Leptospermum laevigatum*, on the relatively sheltered northeast slopes of coastal hills which descend to Main Creek. In mid 1986, it was estimated that about 65% of *Banksia integrifolia* individuals were infested, but that apparently uninfested trees were interspersed amongst infested trees. This patchiness is typical of the early stages of tree decline in *Eucalyptus* (Landsberg 1988) and may have been an early indicator of *Banksia* decline.

As it was likely that significant damage to the canopy and inflorescences of *Banksia integrifolia* was occurring on the Mornington Peninsula, and that some action to control the level of moth related

Fig. 1. Branchlets of *Banksia integrifolia* var. *integrifolia* heavily infested with xyloryctid larvae.

damage may be necessary, an assessment of the *Banksia integrifolia*-xyloryctid moth association was carried out during 1986 and 1987. The study aimed to identify the species of moth(s) involved, and to determine the impact of moth infestation on the severity of canopy dieback, the regrowth of foliage, and the reproductive capacity of *Banksia integrifolia.*

METHODS

Moth identification and life cycle

Larval shelters from separate trees were collected from Main Creek (lat. 38°29′, long. 144°56′) at intervals between September 1986 and June 1987 and examined. Specimens required for measurements were removed from the shelter, killed in alcohol, and measured under ×40 magnification using a graticule. Head capsule width and body length were measured for a total of 330 larvae. A frequency distribution of head capsule width was used to indicate the number of larval instars, and the larval growth constant was determined using Dyar's law (Gillott 1980). A number of intact shelters were kept at a constant 10°C, and at room temperature (Scott 1982), to observe the development of larvae, pupa and adult moths. Moth species were identified by Dr E. Nielson, Division of Entomology, CSIRO, Canberra. Microscopic examination was also carried out to determine the presence of larvae in new normal foliage, new normal foliage regrowing from infested foliage, and dead inflorescences.

Dieback, infestation and regrowth of Banksia

Fourteen trees of *Banksia integrifolia* were tagged at Main Creek and at an uninfested population at Mt Martha (lat. 38°17′, long. 145°00′). Variables assessed at Main Creek were new normal leaf growth, new leaf growth after infestation, canopy

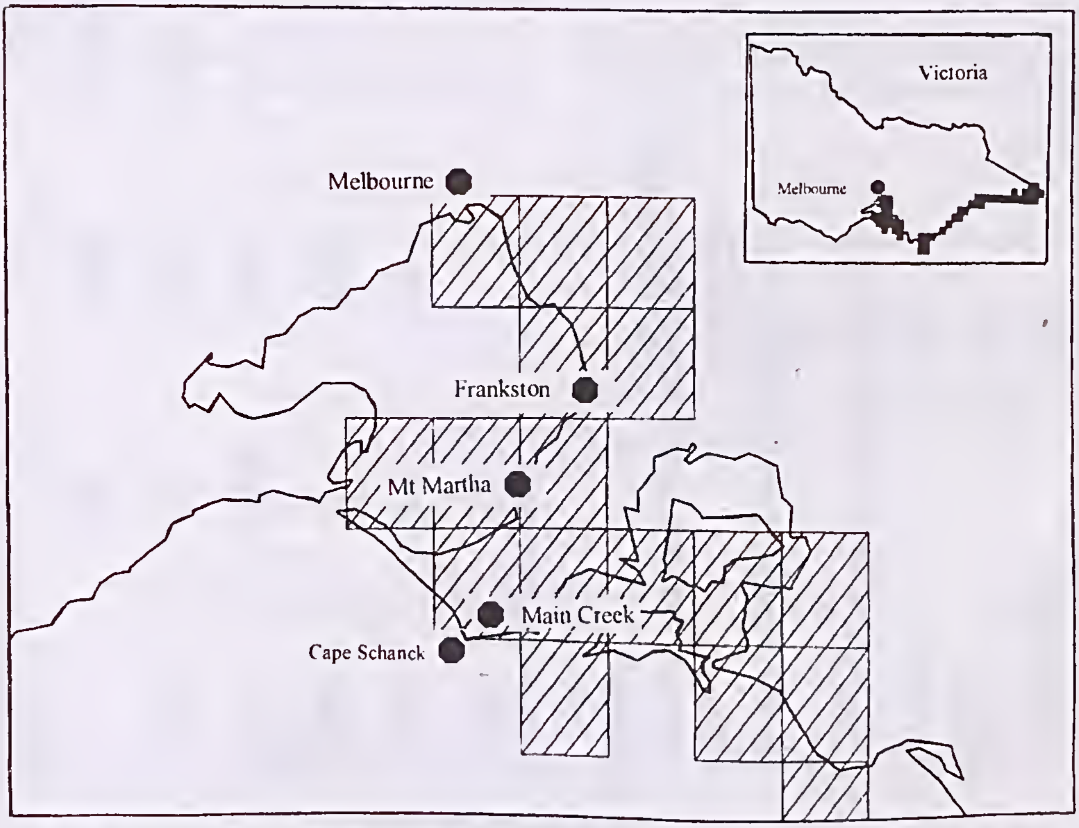

Fig. 2. Distribution of *Banksia integrifolia* var. *integrifolia* in Victoria (insert), and the location of the two study sites at Mt Martha (lat. 38°17′, long. 145°00′) and Main Creek (lat. 38°29′, long. 144°56′).

dieback, larval infestation, and shelter cover. All were scored as a percentage of the total canopy cover of each tree. Variables were recorded monthly between January and July 1987 at Main Creek. Tree girth was also recorded at Main Creek and used as an indirect measure of tree age. New normal leaf growth was estimated from the tagged trees at Mt Martha in January, February and July 1987. All percentages were arcsine transformed for analysis and display (Sokal & Rohlf 1995).

Reproductive capacity of Banksia

Twenty-four developing inflorescences on nine trees at Main Creek, and twelve inflorescences on four trees at Mt Martha were tagged, and their length measured from February 1987 to June 1987, when flowering finished. The number of developed follicles was counted on 11 of the tagged inflorescences at Main Creek and 12 tagged inflorescences at Mt Martha. A further 12 inflorescences were tagged at both sites in August 1986, the number of follicles counted and covered with a mesh bag to catch seeds which were released. Any of the tagged inflorescences which died or failed to complete flowering were examined microscopically for larval presence.

RESULTS

Moth identification and life cycle

Two species of moth, *Xylorycta parabolella* Walker and *Scieropepla* sp. (Lepidoptera : Oecophoridae : Xyloryctinae) (Nielsen et al. 1996), have been identified. However, determining the life cycle of the moths from specimens kept at 10°C constant temperature proved difficult as the larvae only survived within the shelter. Isolating larvae for observation resulted in reduced activity and appeared to slow down larval growth. Larvae which were observed for four months showed little change over this time. Observations of the pupa suggest that the moth emerged about one month after pupation, but there were too few observations to confirm this.

Six instars were indicated for both species. As the proportionate increase in head size from one instar to the next is constant (Dyar's law), instar head sizes should occur as discrete clusters of size rather than as a continuous range of head sizes. The frequency distribution of larval head capsule width indicates four definite clusters at 0.35, 0.5, 0.7, and 1.0 and two less pronounced clusters at 1.4 and 2.0 (Fig. 3).

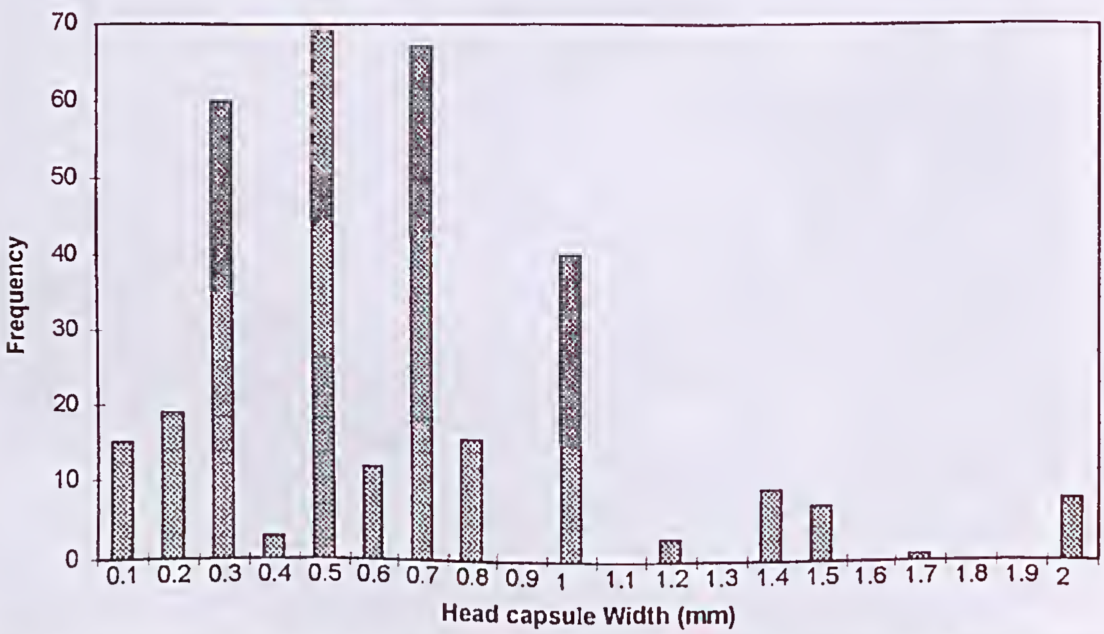

Fig. 3. Frequency distribution of the head capsule widths for larvae of *Xylorycta parabollela* and *Sceiropepla* sp.

Although few pupa (n = 20) were recovered from the shelters, two sizes were found; one 10 mm long and 2 mm diameter and one 7 mm long and 1.5 mm diameter. A small, fragile *Scieropepla* moth emerged from the small pupa and normal sized *Scieropepla* and *Xylorycta* from the larger pupa. It is not known if the small *Scieropepla* moth was the same species as the larger *Scieropepla* moth, but it is likely as sexual dimorphism is known for species in the Xyloryctinae (Nielsen & Common 1991).

The shelters contained many small larvae during January and February (Fig. 4) with predominantly 1st, 2nd and 3rd instars present. Relatively higher proportions of new foliage were produced during January and February (Fig. 5), and this appears to have provided suitable conditions for rapid development of the larvae and a peak of pupation in March. Larvae in the 4th and 5th instar were generally present during March, April and May, and 6th instar larvae were present in June. A second pupation peak was also recorded for June (Fig. 6).

Dieback, infestation and regrowth of Banksia

The percentage of canopy dieback in *Banksia integrifolia* did not vary significantly from about 4% between February and July 1987 (mean = 4.0 ± 0.01), although dieback was significantly lower in January 1987 at about 1.7% (mean = 1.7 ± 0.07, df = 89, p = 0.006). Canopy dieback was not correlated with tree age, as indicated by girth (r = −0.32; p = 0.271, df = 12), but was correlated with percentage infestation (r = 0.74; p = 002, df = 12) and with percentage shelter cover (r = 0.63; p < 0.001, df = 54).

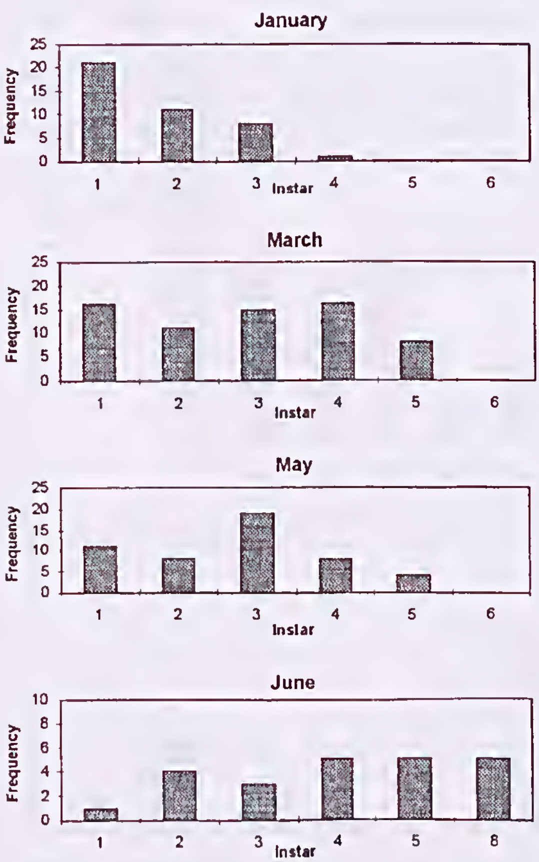

Fig. 4. Frequency of larval instars of *Xylorycta parabollela* and *Sceiropepla* sp. for January, March, May and June 1987.

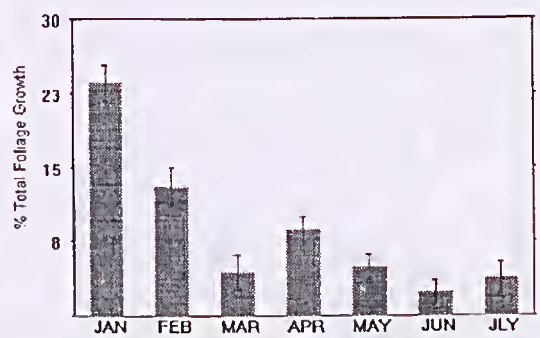

Fig. 5. Mean per cent (± s.e.) total foliage growth at Main Creek for January to July 1987. Percentages have been arcsine transformed.

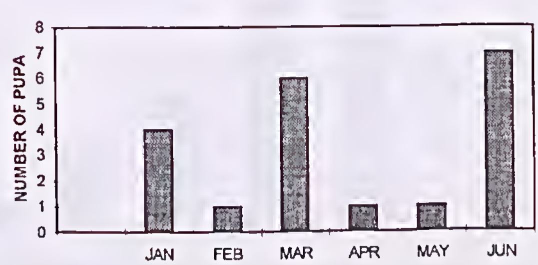

Fig. 6. Distribution by month of pupae (n = 20) of *Xylorycta parabollela* and *Sceiropepla* sp. recovered from shelters between January and June 1987.

New normal foliage growth of *Banksia integrifolia* at both Main Creek and Mt Martha began in November, and was measured between January and July 1987. Normal foliage growth virtually ceased during March to May, but trees at Main Creek had a second growth period in June–July (Fig. 7). This second growth period did not occur at Mt Martha. Generally, six buds appeared, of which five developed into leaves and the sixth into an inflorescence. The subsequent growth of branchlets was usually very rapid if unimpeded by infestation.

Larval infestation is associated with the availability of new leaf growth, and occurs after the numerous ovoid, opaque eggs are deposited in the leaf buds. The new leaf buds ceased to grow normally and became clumped and malformed (Fig. 1). The malformed tissue was very soft and spongy, and tunnelling was found in the stems and petioles of these malformed leaves. Tunnels were usually occupied by one larva, while many small larvae were found amongst the tightly clumped leaves. Numerous nematodes were also found in association with the malformed leaves. As the infestation developed, the larvae consumed the entire branchlet of new leaves. Regeneration arising from malformed, infested branchlets occurred in February, March, April and May 1987 (Fig. 8), and these flushes of regeneration appeared to outgrow the infestation. Foliage suitable for larvae to feed on during the March–May period resulted almost entirely from regrowth of new foliage from infested brachlets, as the growth of new foliage from uninfested branchlets at Main Creek had decreased significantly from January through to May (Fig. 8).

Reproductive capacity of Banksia

The growth of the inflorescences at Main Creek and Mt Martha was rapid during February to April, but slowed during May and June as the inflorescences reached their final length and finished flowering. Flowering was complete by June at Main Creek, and by July at Mt Martha. There was no significant difference in the final size of inflorescences at either location (Table 1). Some of the tagged inflorescences at Main Creek died unexpectedly, and on examination, larvae were found tunnelling in the inflorescence rachis. Although *Scieropepla* larvae are known to tunnel in *Banksia* inflorescences (Common 1970; Scott 1982) these larvae did not appear to be xyloryctid larvae, and may have been a species of *Arotrophora*

Fig. 7. Mean per cent (±s.e.) normal foliage growth for January to July 1987 for Main Creek (MC) and Mt Martha (MM). Percentages have been arcsine transformed.

larvae which are widespread and significant predators of *Banksia* inflorescences (Scott 1982; Zammit & Hood 1986; Wallace & O'Dowd 1989).

Quantifying seed production by catching released seeds in mesh bags was unsuccessful at Main Creek as the bags and some of the larger inflorescences were removed by vandals. Therefore a comparison of actual seed production between the infested and uninfested populations of *Banksia integrifolia* sites was not possible. However, seed capture at Mt Martha was successful with 10.2 ± 2.3 seeds per inflorescence recorded. It is also noteworthy that the developed follicles of most of the tagged inflorescences ($n = 24$) opened and released their seeds (Table 1). Reproductive capacity was estimated using the number of developed follicles per inflorescence. The mean number of developed follicles per inflorescence produced by infested trees at Main Creek was not significantly different from the number produced by uninfested trees at Mt Martha (Table 1).

DISCUSSION

Two species of moth, *Xylorycta parabolella* Walker and *Scieropepla* sp. (Lepidoptera : Xyloryctinae), have been identified from the infested foliage of *Banksia integrifolia* . Species from the Xyloryctinae have been positively associated with damaged inflorescences of *Banksia ericifolia* and *Banksia oblongifolia* (Zammit & Hood 1986), and *Banksia spinulosa* (Wallace & O'Dowd 1989), and several *Xylorycta* spp. have been recorded from *Banksia*

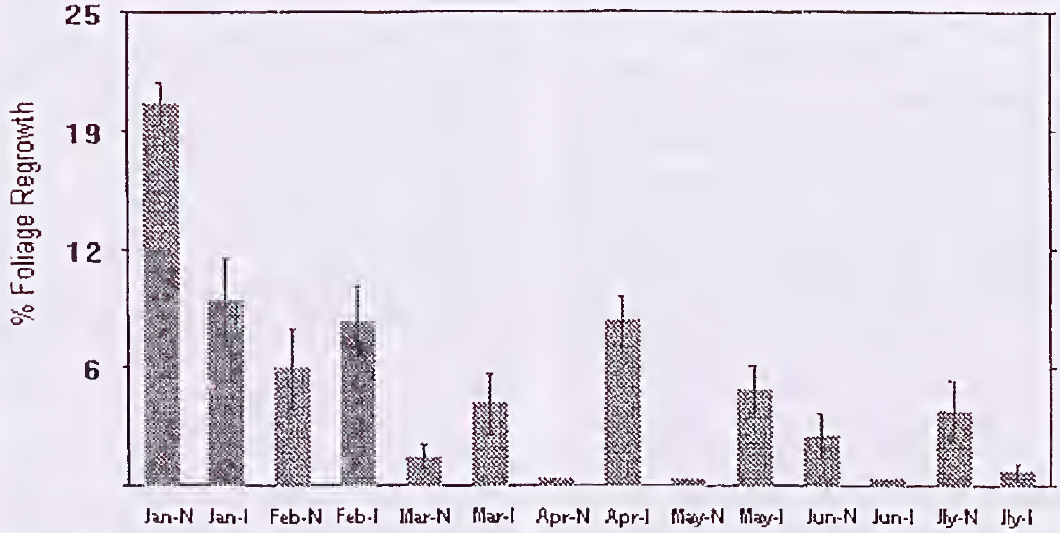

Fig. 8. Mean per cent (± s.e.) regrowth of infested (I) and non-infested (N) foliage at Main Creek for January to July 1987. Percentages have been arcsine transformed.

Inflorescence characteristics	Mt Martha	Main Creek	Significance ($p = 0.05$)
Open follicles	27.4 ± 4.6 (12)	31.7 ± 6.4 (12)	ns
Closed follicles	0.7 ± 0.4 (12)	3.9 ± 2.0 (12)	ns
Percentage open follicles	98 ± 0.5 (12)	93 ± 1.0 (12)	ns
Seeds per inflorescence	10.2 ± 2.3 (12)	not available	—
Inflorescence length (mm)	75.4 ± 5.7 (11)	71.2 ± 3.8 (21)	ns
Developed follicles per inflorescence	28.1 ± 4.5 (12)	35.6 ± 6.3 (11)	ns

Table 1. Mean (± s.e.) numbers of open and closed follicles, the % open follicles, and mean number of seeds per inflorescence for *Banksia integrifolia* var. *integrifolia*. Inflorescence length and number of developed follicles (mean ± s.e.) for uninfested (Mt Martha) and infested (Main Creek) trees of *Banksia integrifolia* var. *integrifolia*. Numbers of observations given in ( ); ns = p>0.05.

littoralis, *B. grandis*, *B. telmatiaea* and *B. attenuata* (Scott 1982). However, they have usually been present in low numbers, and much of the seed and inflorescence damage seems to be caused by *Arotrophora* spp. (Lepidoptera : Tortricidae : Tortricinae) (Scott 1982; Zammitt & Hood 1986; Wallace & O'Dowd 1989; Röhl & Wood 1994) rather than *Xylorycta* spp. or *Scieropepla* spp. The main damage associated with a *Xylorycta* species was to the leaves and stems of *Banksia* rather than the flowers and seeds (*Xylorycta* sp. 5; Scott 1982). Results from Main Creek are consistent with this, as inflorescences which died unexpectedly were found to contain larvae which may have been a species of *Arotrophora* rather than xyloryctid species, but foliage and branchlet damage was always associated with *Xylorycta* sp. and *Scieropepla* sp.

Flowering and seed production in *Banksia* varies from year to year (McFarland 1985; Copland & Whelan 1989) and from species to species (Whelan & Burbidge 1980; Collins & Rubelo 1987; Copland & Whelan 1989). *Banksia integrifolia* is typical of the eastern Australian species, which flower in autumn (Collins & Rubello 1987). *Banksia integrifolia* L. f. var. *compar* (R. Br.) Bailey, flowers between February and June–July (McFarland 1985), and flowering for *Banksia integrifolia* L. f. var. *integrifolia* at Mt Martha and Main Creek was complete by June 1987. Short inflorescence lengths of 75.4 ± 5.7 mm and 71.2 ± 3.8 mm (Table 1) were also consistent with the 77.8 ± 3.6 mm recorded by McFarland (1985).

Seed production in *Banksia* is also highly variable (Scott 1982; Cowling et al. 1987). Seed set in Western Australian species can vary between 3 and 42 seeds per inflorescence (eg. table 1 in Cowling et al. 1987). Seed production per inflorescence for *Banksia integrifolia* L. f. var. *integrifolia* at Mt Martha (10.2 ± 2.3; Table 1) is low when compared to seed production for other eastern Australian species (22.9 ± 15.1 for *B. ericifolia* [Zammit & Hood 1986]; 47.6 ± 4.0 for *B. spinulosa* [Vaughton 1990]). However, it is well within the overall seed production range for *Banksia*.

The degree of serotiny also varies. Strongly serotinous species (eg. *Banksia attenuata*, *B. serrata*, *B. spinulosa* var. *cunninghamii*) retain a significant proportion of the annual seed production in the canopy seed bank (Cowling et al. 1987; Lamont & Barker 1988) while weakly or non-serotinous species (eg. *Banksia integrifolia*, *B. marginata* and *B. menziesii*) release seed as it ripens (Wrigley & Fagg 1989). Viable *Banksia* seed does not accumulate in the soil (Cowling et al. 1987; Specht 1994) and successful regeneration of *Banksia* relies on canopy stored seed in serotinous species, or on adequate annual seed production in weakly serotinous species. Between 93% and 98% of developed follicles of *Banksia integrifolia* at both Main Creek and Mt Martha opened and released seed, confirming the low levels of canopy stored seed and the dependence of *Banksia* woodland regeneration on annual seed production. Weakly serotinous species also tend to have higher levels of seed predation (Cowling et al. 1987), and any loss of *Banksia integrifolia* seed due to xyloryctid moth damage has the potential to reduce the long term regeneration capacity of the species.

Although no counts of seeds per inflorescence were available for Main Creek, the impact of xyloryctid moth infestation on reproductive capacity can be estimated using the number of developed follicles as a measure of seed set (Whelan & Burbidge 1980; Paton & Turner 1985; Copland & Whelan 1989; Wallace & O'Dowd 1989). Reproductive capacity does not appear to be reduced in infested trees, as the number of developed follicles per inflorescence (Table 1) and the number of open follicles per inflorescence at Main Creek was not significantly different from the number at Mt Martha (Table 1). As Cowling et al. (1987) suggest that insect-damaged follicles in weakly serotinous species do not open, it could be argued that opened follicles on inflorescences at Main Creek had successfully produced and released seed, and that the numbers of seeds per inflorescence at Main Creek was comparable with Mt Martha. That is, the infestation of xyloryctid moths at Main Creek had not reduced seed production beyond the background level of seed predation losses.

Overall canopy damage for the *Banksia integrifolia* woodland at Cape Schanck was quite low, at about 4%. However, there was considerable variation between trees, ranging from no dieback in uninfested trees through to between 1% and 10% dieback in infested trees. Canopy dieback was not related to tree age and it is unlikely to be a response to plant stress or low resource availability (Landsberg & Gillison 1995). Up to 36% canopy damage caused by salt spray has been recorded for *Banksia integrifolia* in coastal situations (Morris 1992), however, as the infested area of *Banksia integrifolia* at Cape Schanck occupies northeast slopes which are relatively sheltered from the prevailing southerly and westerly winds, the observed canopy dieback is unlikely to result from salt spray.

Canopy damage caused by insect herbivores is well recognised for many *Eucalyptus* species (Ohmart & Edwards 1991), and the microlepidopteran group Oecophoridae, to which *Xylorycta* and *Sceiropepla* belong, is one of the most common groups of eucalypt defoliators (Ohmart et al. 1983) and leaf-litter decomposers (Common 1980). *Xylorycta* and *Sceiropepla* are considered to be specialist herbivores on *Banksia* (Powell 1980; Nielsen & Common 1990), and the high positive correlations between canopy dieback and the proportions of tree infestation and shelter cover strongly support the proposal that it is infestation by these species which is responsible for the canopy damage in *Banksia integrifolia*.

The larvae of both *Xylorycta parabolella* and *Scieropepla* sp. feed on the new leaf and branchlet tissue of *Banksia integrifolia*, and eventually consume the entire branchlet. Foliage suitable for xyloryctid larvae to feed on resulted almost entirely from flushes of new growth. Similar relationships have been reported (eg. Carne 1965, in Landsberg 1988), and infested or dieback trees also tend to produce more new foliage, and out-of-season regrowth, as a response to prior infestation (Landsberg 1988). It is possible that this regrowth foliage represents a different quality food source for the larvae (Landsberg 1990), and it may be preferred as oviposition sites (Wilcox & Crawley 1988). However, the malformation of leaves of *Banksia integrifolia* may be caused by nematodes rather than the xyloryctid larvae. Nematodes were found in association with moth eggs and larvae, and a similar association between the gall-forming nematode *Fergusobia currie* and the fly *Fergusonia nicholsoni* has been recorded in *Eucalyptus* (Currie 1937).

Normal foliage growth was negligible during autumn and early winter, but the regeneration of foliage on infested trees was prolific. The subsequent growth of branchlets was usually very rapid, and frequently outgrew the infestation. This suggests that *Banksia integrifolia* is able to recover, at least in the short term, from the defoliation caused by xyloryctid moth larvae, and that active management to reduce the levels of larval infestation is not warranted. However, given the likelihood of re-infestation of regrowth foliage (Landsberg 1990), the longer term impacts of repeated re-infestation on tree canopy dieback and overall tree health need to be assessed. Although xyloryctid moth infestation does not appear to reduce seed set, and individual trees are able to recover from canopy damage, repeated infestation may still pose a threat to the survival of these *Banksia integrifolia* remnants, and to the xyloryctids themselves through loss of their host species. The extent and seasonality of infestation by xyloryctids over the whole of the range of *Banksia integrifolia* var. *integrifolia*, and the degree of dependence of these moth species on *Banksia*, also need to be determined. Moth infestation should not be viewed as a simple pest problem requiring control, and future management of *Banksia* woodland needs to emphasise habitat integrity for *Banksia*, so both *Banksia* and these xyloryctid moths species survive in the long term.

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